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# The SNS Moderator Demonstration Facility

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**Abstract.** We describe a moderator demonstration facility at the Spallation Neutron Source (SNS). We will use the Beam Test Facility (BTF) at SNS to provide a moderator neutronics test stand with which we will verify the performance gains expected from the innovative moderator concepts central to the SNS Second Target Station. These concepts include large-volume para-hydrogen moderators and high-brightness moderators, as well as new moderator materials. The BTF provides a test facility for the new Radio-Frequency Quadrupole accelerator (RFQ) to be installed at SNS and produce a pulsed H<sup>-</sup> beam of 2.5 MeV energy. We will add to the BTF a beam chopper similar to that already used in the SNS at the RFQ exit, various beam transport components, a neutron-producing target, a cryogenic moderator test stand, a reflector-shielding assembly, and a performance assessment neutron beamline.

## 1. Introduction

The Spallation Neutron Source facility is currently developing the technical design for a Second Target Station (STS). One of the essential aspects of the STS concept is a high-brightness para-hydrogen moderator—this moderator will significantly outperform the coupled moderators on the first target station (FTS), with a significant fraction of that performance gain requiring complete conversion to equilibrium levels of para-hydrogen (approximately 99.8% at 20 K). [1, 2] In the design of the FTS, the moderators were designed to be relatively insensitive to the exact ortho/para-hydrogen fraction, with a consequent loss in performance. The success of the proposed STS concept relies on the a) reliable prediction of the neutronic performance advantages of a large-volume or high-brightness para-hydrogen moderator, b) the diagnostic capability to assess the ortho/para-hydrogen fraction in an operating moderator, and c) the ability to understand the interaction between natural conversion to para-hydrogen, radiolysis-induced back-conversion to ortho-hydrogen, and system catalysis. [3] These are long-standing challenges in the implementation of hydrogen moderators at high-power neutron sources. In short, successful execution of the Second Target Station concept requires solving these challenges.

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We will install and implement a moderator neutronics demonstration capability at the Beam Test Facility (BTF) at the Spallation Neutron Source with which we will verify these performance gains. These concepts include both high-brightness and large-volume para-hydrogen moderators. We will add to the BTF a proton beam chopper similar to that already used in the SNS at the RFQ exit, various proton beam transport components, a neutron-producing target, a cryogenic moderator test stand, a reflector-shielding assembly, and a performance assessment neutron beamline. The Moderator Demonstration Facility (MDF) will provide the ability to test a large-volume para-hydrogen moderator in a prototypic configuration, simultaneously measuring the neutronic performance of the moderator concept central to the anticipated STS gains and developing the instrumentation necessary to provide that performance in a production environment. Additional moderator concepts proposed for STS as well as FTS can also be tested at this facility, including the high-brightness moderators involving significantly restricted (transverse) moderator views. Testing these moderators requires a wing moderator configuration, not available at existing test facilities worldwide. [4, 5]

## 2. Project Overview

We envision four main components to the Moderator Demonstration Facility project:

- (i) Provide a proton chopper and beam transport system to deliver 50 mA (peak) of 2.5 MeV protons from the BTF to a suitable neutron-producing target with pulse width between 0.5 and 10  $\mu$ s.
- (ii) Provide a neutron-producing target and reflector assembly optimized to represent prototypic moderator illumination (that is, moderator illumination from the target and reflector should replicate that predicted for the STS concept and accommodate large-volume and high-brightness moderator concepts).
- (iii) Provide an instrumented moderator vessel, neutronically equivalent to a production moderator proposed for STS, but additionally capable of in situ Raman spectroscopy for assessing the spin-state distribution of the hydrogen in the moderator vessel, as well as providing ultraviolet irradiation of the moderating material to mimic the radiolysis rates in the production STS moderator independently from the neutron irradiation associated with measuring the neutronic performance.
- (iv) Provide a neutron beamline for the assessment of neutronic performance of the prototypic moderator configuration as influenced by radiolysis and external catalysis.

Each of these four components is essential to the successful assessment of the STS volume moderator concept; each of these four components is also unique—no test facility currently exists that can adequately answer these questions in a prototypic manner.

## 3. Proton Chopper

The RFQ system itself is not capable of providing proton pulses of less than around twenty microseconds width, significantly larger than we prefer in order to assess the moderator slowing-down performance. SNS has developed a MEBT chopper system [6] to provide high-quality proton beam chopping prior to acceleration in the LINAC, in order to provide a beam-free extraction window in the accumulator ring proving sub-microsecond pulses to the SNS FTS (and eventually STS). The MEBT chopper system enables beam rejection of more than four orders of magnitude with rise/fall times of less than five nanoseconds. In SNS itself, this chopper imposes a beam-free period of approximately 300 ns in between beam mini-pulses lasting 700 ns; in the BTF-based moderator test facility we propose, we would instead use this chopper system to provide single pulses of variable duration as required for assessing different moderator performance characteristics; longer durations (up to ten microseconds) for more neutrons at

very low energies where we can tolerate the resolution effects, shorter durations (around one microsecond) for prototypical studies going up to 0.5 eV, and even shorter durations (as low as 500 ns) for detailed investigation of the slowing-down capabilities of different moderator configurations. This ability to provide short-duration pulses is essential for the successful study of moderator performance for short-pulsed neutron sources. This capability is not currently available at low-powered test facilities such as LENS (which has a minimum proton pulse width around twelve microseconds). While sub-microsecond pulse durations are available at electron-bremsstrahlung facilities such as at Hokkaido University in Japan, those facilities necessarily provide copious fluxes of high-energy photons, complicating the study of moderator performance independently of radiolytic dissociation rates. The use of the SNS-developed MEBT chopper system is an essential and unique feature for a short-pulsed moderator test facility.

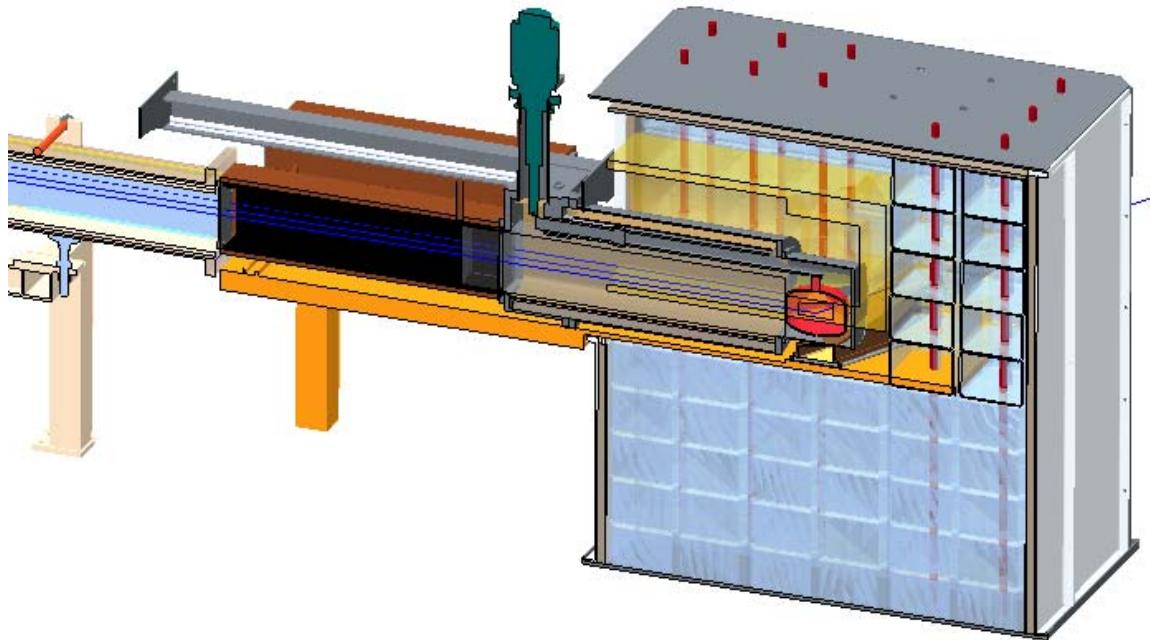
#### 4. Target-Reflector Assembly

Most facilities have (for good reason) chosen to optimize the target apparatus to maximize neutron production. As a result, facilities such as those at LENS and Hokkaido University provide non-prototypic moderator illumination. We will optimize this facility to provide prototypic moderator illumination, with the recognition that the resulting characterization will require more advanced measurement techniques to offset the reduced intensity. At 2.5 MeV, protons produce far more neutrons off of lithium than off of beryllium (thick-target yields of  $10^9$  n/ $\mu$ C vs  $10^8$  n/ $\mu$ C). Additionally, the neutrons coming from the endothermic lithium reactions are of significantly lower energy (strictly less than 0.8 MeV) than the exothermic beryllium reactions (mean energy of around 5 MeV). Accordingly, the shielding requirements are much reduced for a lithium target (on a per source neutron basis). Finally, with a primary neutron energy below 1 MeV, we will drastically reduce activation levels in the target-moderator-reflector assembly during operations; experience at LENS indicates that the primary source of residual dose is  $^{24}\text{Na}$  from (n, $\alpha$ ) reactions on aluminum, with a threshold of a few MeV. While a lithium target is somewhat challenging at these powers, the 50 mA peak current is strongly diminished by a duty factor of less than  $10^{-5}$ . Additionally, our desire for a prototypic moderator illumination will push us toward a very extended target geometry—using a beam spot of greater than  $300\text{ cm}^2$ , significantly reducing power deposition in the vulnerable lithium material.

#### 5. Instrumented Moderator System

One nominal moderator vessel we would study will be neutronically similar in geometry to the volume moderator proposed [7] for the STS: a cylinder of diameter 15–20 cm, of height 10–15 cm. Such a moderator will, in some ways, represent a bounding case for accommodating large moderators. This moderator vessel will contain liquid or supercritical hydrogen at pressures less than 20 bar. Optical feed-throughs on the vessel will admit laser probe and collection optics for *in situ* Raman spectroscopy to study the spin-state distribution of the hydrogen. Additional ports will permit separately-controlled UV illumination to simulate the radiolysis effects of prototypic beam powers. The moderator vessel will be mounted on a standard closed-cycle refrigerator cold head similar (for maintenance convenience) to those used throughout the SNS facility. The moderator assembly will share vacuum space with the initial portion of the neutron beamline, as shown in Figure 1. This single penetration offers a number of functional advantages, including:

- permitting gas feed lines, thermal links, sensor access, and neutron beam egress without compromising moderator decoupling (when desired),
- horizontal moderator assembly extraction along a track, eliminating crane requirements and shield unstacking, while more reproducibly positioning the moderator system relative to both the target and the characterization beamline,



**Figure 1.** Elevation cross section of the target-moderator-reflector assembly.

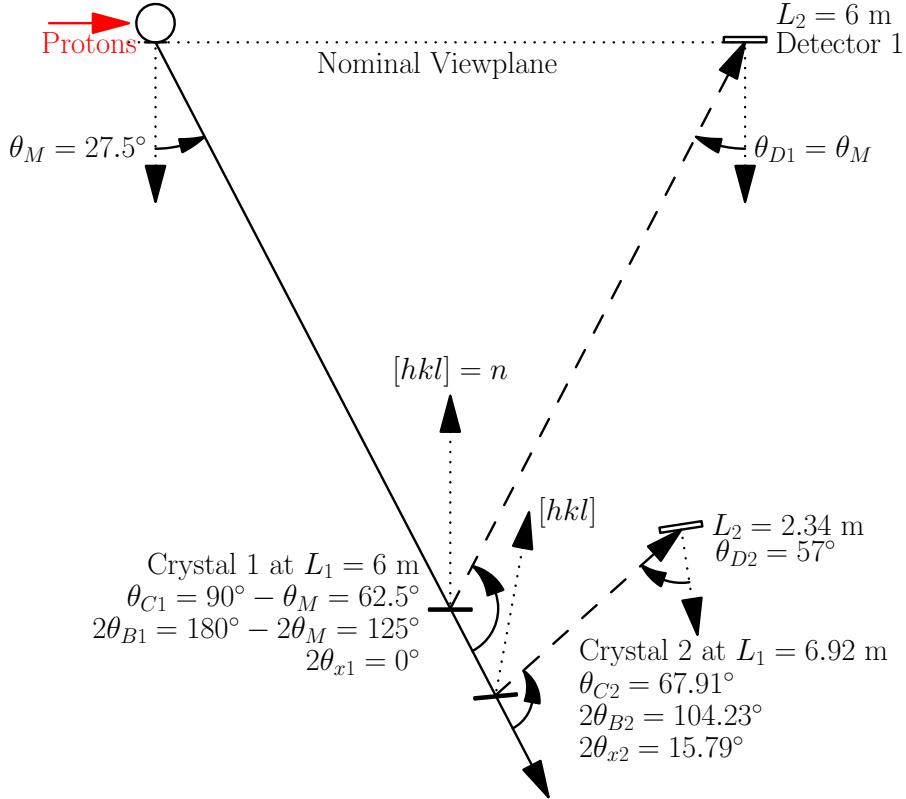
- enabling much larger moderator systems than can be accommodated otherwise, or even large optical components to be placed in the first meter of beamline length.

## 6. Characterization Beamline(s)

A single, dedicated neutron beamline will enable detailed assessment of the neutronic performance of the moderator. In keeping with the prototypic nature of the facility concept, a relatively large-area beam will be permitted to leave the moderator and go down a flight-path of roughly 3–6 m to an array of analyzers and detectors which will measure the energy spectrum of the neutron beam from 0.1 meV to 10 eV, the energy-dependent emission time distribution of the neutron beam from 0.8 meV to 1 eV, and the energy-dependent spatial distribution of moderator emission intensity with position resolution (on the moderator surface) of order five millimeters. A conceptual layout for the emission time analyzers is shown in Figure 2. The single beamline hosts two arrays of analyzer crystals, both in fully time-focused geometry. [8] The first array (based around a fluorophlogopite analyzer array) will probe low energies (down to 0.3 meV), with good density of coverage at in the vital 2–10 meV range. The second array (based around an off-cut high-mosaic copper analyzer array) will provide significant coverage overlap at intermediate energies, but go significantly higher as well (up past 1 eV). Additionally, the independent analyzer arms will provide a cross check, improving our knowledge of instrument resolution.

## 7. Performance Estimates

We base performance estimates for this test facility on comparisons with the LENS facility [4] as used for moderator development. When used for short-pulsed moderator development measurements, LENS provides approximately 12  $\mu$ A of 13 MeV protons on a beryllium target



**Figure 2.** Layout of the emission time analyzer arrays neutron characterization beamline.

during a  $12 \mu\text{s}$  pulse at up to 40 Hz, giving a primary source intensity of around  $6 \times 10^{11} \text{ n/s}$ . The LENS facility hosts two neutron beam-lines used for moderator characterization experiments: a small-angle neutron scattering instrument (SANS) temporarily modified to provide spectral and emission time characterization and a dedicated Moderator-Imaging Station (MIS) providing energy-dependent brightness distribution on the moderator surface. Using  $3 \mu\text{A}$  of 2.5 MeV protons (a  $1 \mu\text{s}$  pulse width at 60 Hz) on a lithium target at BTF will reduce the primary source intensity by two orders of magnitude as compared to LENS. Additionally, the primary spectrum is much lower energy, with a 0.8 MeV maximum instead of a 5 MeV average. We will configure the BTF target-moderator-reflector system in a wing configuration as appropriate for prototypic SNS use, both FTS and STS, and essential for testing either volume-moderator or high-brightness concepts. Wing configurations are less tightly coupled to the primary neutron source than slab configurations; as a result, our base moderator brightness (for the same conventional moderator) at BTF (when operated with a  $1 \mu\text{s}$  pulse width) will be around a factor two hundred lower than at LENS. While this is a significant disadvantage to overcome, LENS is configured primarily for neutron scattering applications, and is dramatically inefficient for moderator characterization. We will eliminate the ability to extract multiple distinct neutron beam-lines. We will employ analyzer arrays of approximately  $300 \text{ cm}^2$  in fully time-focused geometry, where the SANS-beamline collimation at LENS limits the analyzer to around  $20 \text{ cm}^2$ . This analyzer array will

be placed closer to the moderator under test than the 8.5 m position at LENS (again dictated by the SANS-optimized geometry). As a result, the time-averaged beam incident upon the emission-time analyzer at the BTF facility will be reduced over that at LENS by only a factor three. At LENS, moderator characterization experiments require approximately ten hours of beam to provide adequate statistics for emission-time distribution measurements. At the BTF facility, accruing the same total counts will require some thirty hours of beam, but the sharper primary source pulse will provide the same ability to assess a given neutron pulse shape with far less statistics. Accordingly, we expect that the most time-consuming portion of a moderator characterization experiment, the measurement of emission-time distributions, will be comparable at the BTF facility to that at LENS, were the LENS target-moderator-reflector assembly to permit the study of large-volume and high-brightness moderators.

## 8. Future Outlook

This test facility is intended directly and primarily to demonstrate that the concepts proposed for the SNS Second Target Station can be successfully deployed. Once that demonstration has been accomplished, we will have a world-class test facility to continue to serve the needs of the SNS and HFIR facilities for the development, both conceptual and prototypic, of new advanced neutron sources. SNS already supports around four weeks worth of moderator development experiments at LENS each year, suggesting an internal demand on an ongoing basis of as much as six-to-ten weeks per year once we have accounted for offset travel costs and different capabilities. Additionally, the moderator test facilities already available world-wide are in considerable demand. We anticipate that a unique test facility as described here would become the premier location for the study of advanced moderators for slow neutron source applications, and would be able to function as a user facility in its own right, similar to those currently available at LENS, Hokkaido University, or the Lujan Center.

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## References

- [1] Gallmeier F, Lu W, Riemer B, Zhao J, Herwig K and Robertson J 2016 *Review of Scientific Instruments* **87** 063304
- [2] Remec I, Gallmeier F X, Rennich M J, McManamy T J and Lu W 2015 *In ANS MC2015 - the Proceedings of the Joint International Conference on Mathematics and Computation (M&C), Supercomputing in Nuclear Applications (SNA) and the Monte Carlo (MC) Method* vol 4 (American Nuclear Society) pp 2713–2726
- [3] Iverson E B and Carpenter J M 2003 *ICANS-XVI, Proceedings of the International Collaboration on Advanced Neutron Sources, Neuss, Germany* ed Conrad H pp 707–718
- [4] Baxter D V, Leung J, Kaiser H, Ansell S, Muhrer G, Iverson E B and Ferguson P D 2012 *Physics Procedia* **26** 117–123
- [5] Kiyanagi Y, Ooi M, Ogawa H and Furusaka M 2003 *Journal of Neutron Research* **11** 3–11
- [6] Aleksandrov A *et al.* 2008 *Proceedings of the European Particle Accelerator Conference* vol 8 URL <https://accelconf.web.cern.ch/accelconf/e08/papers/thpp074.pdf>
- [7] Gallmeier F X 2013 Moderator studies for a SNS short-pulse second target station Tech. Rep. STS03-31-TR0004-R00 Oak Ridge National Laboratory
- [8] Graham K F and Carpenter J M 1970 *Nuclear Instruments and Methods* **85** 163–171